The Grand Challenge in Flight Control

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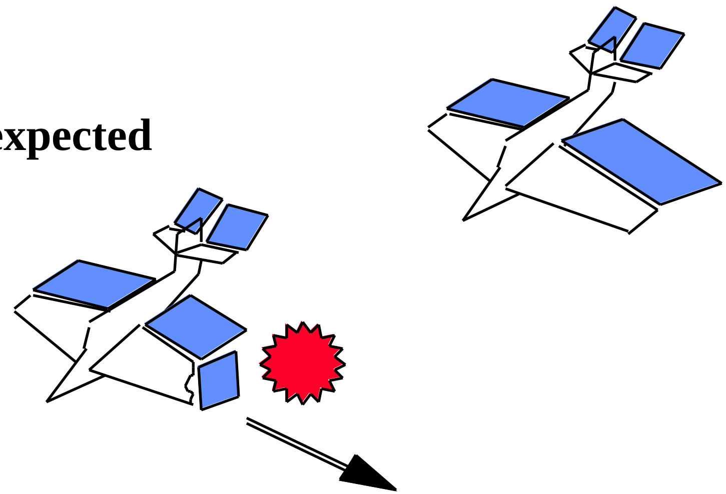
Best Possible Control

Following Physical Damage
During Flight

Battle or other unexpected damage



High level of adapatability required

Examples exist but,

Is the technology here or imminent?

System Requirements

- State of System - Access from aero/control viewpoint
  - What control devices are still functional?
  - What is the existing surface geometry for the vehicle?
- Broadcast Alert - Automatic alert of status and need
- Mission Plan - Develop/modify in light of situation
  - What is best emergency mission from existing options?
    - Landing, ditching options - location?
- Redesign control system to reflect mission selected
- Update - Continually as mission evolves

Examining Approaches that Promise High Adapatbility

- Adaptive Control
  - May be good for highly structured cases but, past experience is dissappointing.
- Neural-Networks
  - Since there is no tie to physics of process, for reasonable behavior, not luck, the system must have seen a like event before, either in real or simulated situations, and be trained to respond properly.
- Physics-Based Schemes
  - Requires adaquate sensors and control devices for implementation
  - Current progress in computer technology offers hope of

Incorporating CFD into flight control systems

Available CFD theories

Viscous, compressible flow

- called Navier-Stokes theory - Most complex

Invicid, compressible theory

- called Euler theory - Still complex but needed for supersonic and transonic flow cases

Theory of choice

Invicid, incompressible theory -

- called potential theory for fluid flow
- can be used for high subsonic with compressibility corrections added
- can be used in conjunction with a boundary layer theory (BLT) to deal with real flowphenonema

Modelling with Potential Flow

Fundamental Relations:

- Continuity Equation -> Potential Equation
- Momentum -> Bernoulli Equation for pressure distributions
- Doublet distributions over wakes -> produce circulation driven by Kutta conditions
- Modelling separation point and bubble generates *effective* surfaces to define potential flow regions

Synopsis of Potential Theory

- Conservation of mass is fundamental equation, $\Delta\Phi = 0$
- **V = grad**(Φ) in (x,y,z) space where **V** is the velocity of a particle at (x,y,z) and Φ is the velocity potential at (x,y,z)
- Requires no vorticity in flow regions considered
- To solve:
  - Green's formula -> Need only grid the near field boundaries -- aircraft surfaces (with separation bubbles) and wakes
  - Panel methods well developed which incorporate far field boundary conditions analytically.
  - Time varying flow results from separation dynamics and deformation of the boundaries, e.g. control surface motions

Synopsis of Potential Theory
-- Time Varying with Conservative Body Forces --

Satisfy potential equation at each instant of time as well as new Bernoulli equation to define pressures :

$$\frac{\partial \Phi}{\partial t} + \frac{\mathbf{w}^2}{2} + \frac{p}{\rho} - U = f(t)$$

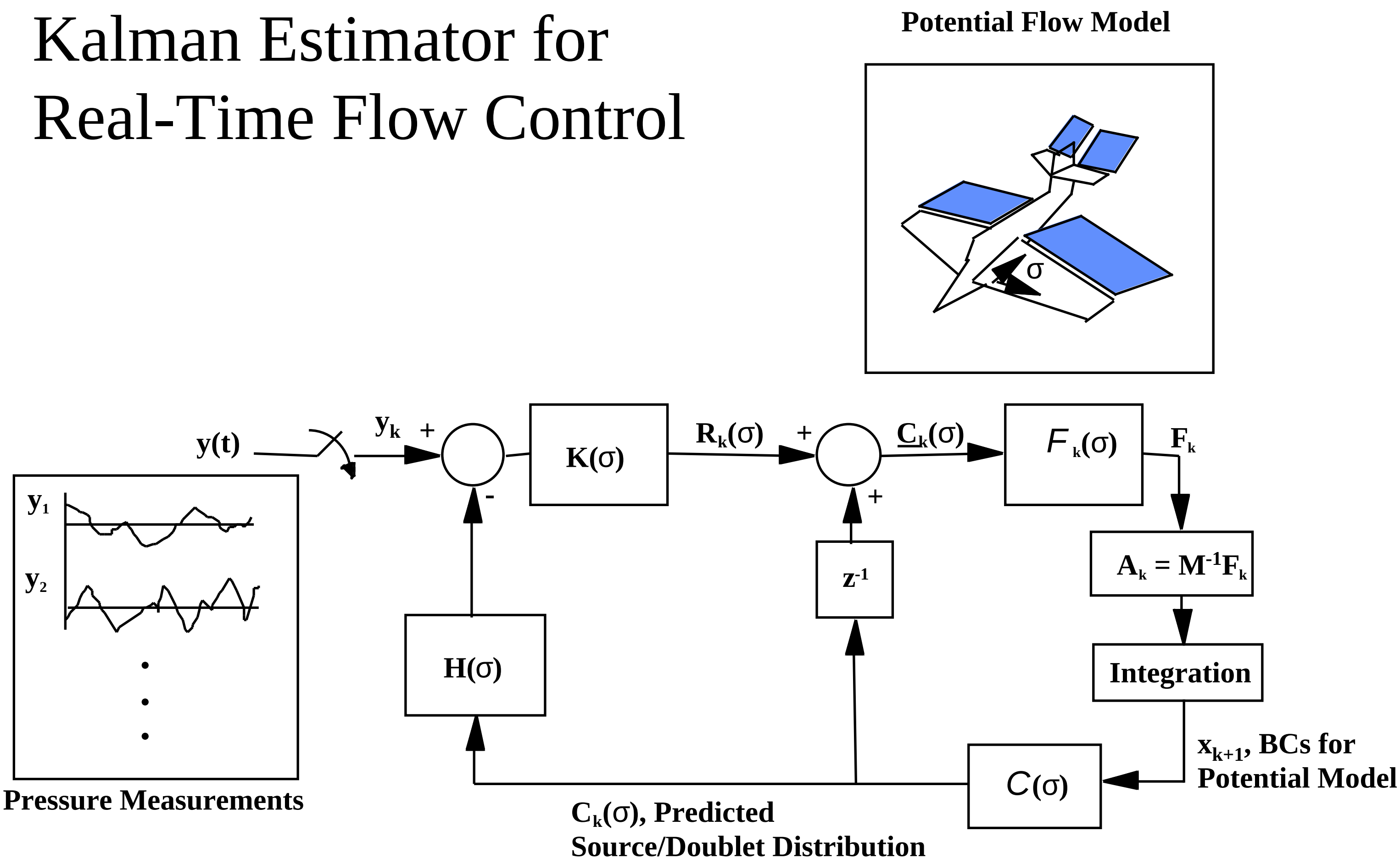
where:

- **t** is time
- **p** is pressure at (x, y, z)
- ρ is fluid density at (x, y, z)
- **U** is the body force potential, usually **- g • Δz**
- **f** ~ usually zero

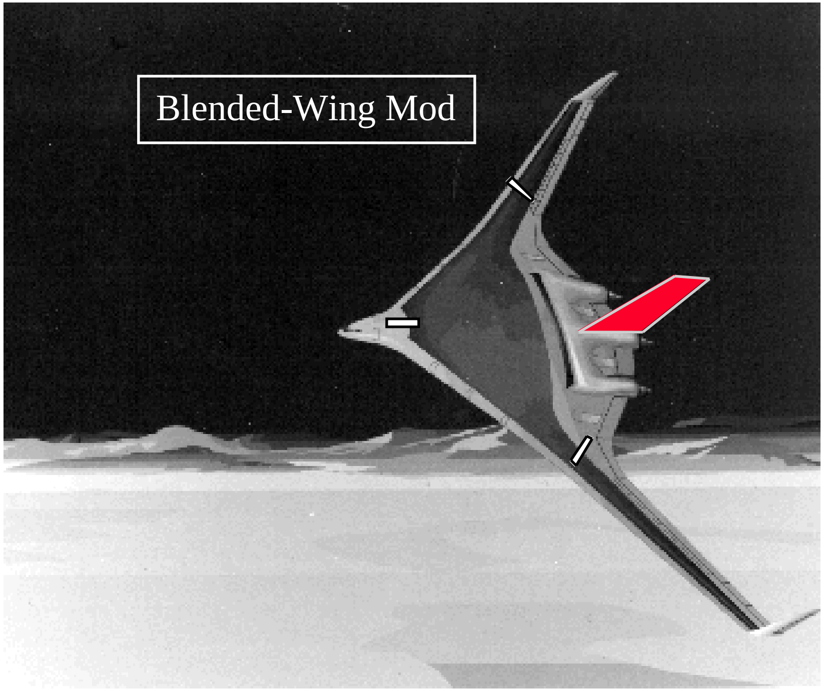
Long Range Plan

- Refine DCB core competency in CFD
  - 2 D Panel code -> basic potential method with boundary layer
  - 3 D code for implementation
- Select target vehicle - Sensor/actuator driven system
  - Need on-line surface grid generation and pressures
  - J. Foster’s RPV, DARPA’s X36 experiment, or other
- Architecture incorporating CFD in a flight control system
  - Study ability to predict - time horizon, correlatablilty
  - Develop prediction, estimation, system ID for on-line tuning
  - Control law studies, design, integration
- Simulation and Fail-Safe Flight Demonstration
  - recover from failure in small target region of vehicle - e.g. add vertical tail to tailless design and blow off - other concepts possible.

Kalman Estimator for Real-Time Flow Control



Fail-Safe Flight Demonstration
- Blended-Wing Model or X36 -



Video

Throw-away vertical stabilizer and rudder

Now, Here’s Mike#@$@%!!

(I’ll try to be quiet.)